Dishwasher history and its role in modern design

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Abstract— **The fundamental steps in the development of electrical technologies have determined their strong diffusion in several applications that were previously hand operated and controlled. The household appliance industry is one of the sectors where this permeation had the major effects, fostering a continuous search for new design perspectives. Capturing such product evolution is fundamental in order to preserve knowledge coming from past experiences, which could act as a stimulus for new technical solutions or socio-economic analysis. Starting from the description of the dishwasher historical evolution, in this paper an approach to preserve such precious knowledge is presented: a functional representation of that knowledge is proposed end its role in modern design is discussed.**

Keywords- product evolution, functional basis, dishwasher electric motor.

I. INTRODUCTION

In the first decades of the XX century the electrical technologies begun to spread in many hand operated and controlled applications. That permeation opened new design perspectives, widening machine capabilities and reducing human efforts, as it has happened to several home appliances such as the dishwasher. Since from its first appearance in Western countries, the dishwasher has been seen as a welcome help and its importance has increased significantly in recent years influenced by new social trends that have made it an essential home appliance.

Nowadays, under an engineering design perspective, a dishwasher can be considered as a complex system, since it integrates mechanical, electrotechnical and electronic features, whose interaction highly influences the cleaning performances of the product. That cleaning effect is the result of 3 physical actions such as: the mechanical impact of water on the load (e.g. pans, plates, cutlery, etc. placed on the two racks); the chemical action of the detergent; the thermal action of the water. While the mechanical effect depends on the rotation speed of the two spryer arms and then on the water pressure (since it strongly influences the rate of mechanical removal and the solubility of soil and detergent during the washing phase), the detergent component chemical reactions are activated by the water thermal energy, electrically heated up at a temperature that depends on the selected washing cycle (from 50-52°C in case of energy saving cycles, until 65°C for the intensive ones with an average consumption of 1,1÷1,2 kWh, even if there is a strong push to decrease such value). At the end of each washing cycle, a pump drains the water up. During the drying phase the water is heated up at about 65÷67°C; that cycle is then the most energy-intensive and for this reason manufacturers are now investing a lot of efforts to make this phase more energy saving. The hot water in turn heats dishes and their heat capacity enables the evaporation of the water film on them. Steam condensation occurs on the tub surfaces and the liquid is then collected and exhausted by the drain pump. A micro-filter and a central plastic wider-mesh filter continuously clean the water during the wash phase: dirty residues are separated and the hydraulic circuit is prevented from being clogged. An electronic system, or a timer, regulate the time duration of the cleaning process with the possibility, in selected models, to delay the start time of the cycle by 3, 6 or 9 hours.

However, modern dishwasher design has come a long way from their original inception. The first systems for washing table furniture can be traced back up to 1850, when J. Houghton obtained a patent [1]. Anyhow, Mrs Josephine Cochrane is commonly acknowledged as the dishwasher inventor: in 1886 she obtained a patent about a manually operated machine capable to wash dishes; that machine worked by spraying soapy water onto dishes held securely within a rack [2].

The first electrical technology introduced in this family of machines was the electrical motor aimed to operate the pump used to circulate the water. Among the firsts, in 1917, Mrs Cochrane patented an electrically powered dishwasher. This invention began to be installed in homes in the 1920s. The diffusion of the dishwasher was limited to restaurants and hotels, mainly because of the high production costs and the unstable social and economical context, deeply influenced by the two World Wars. Thanks also to the new electrical power source, two main solutions were developed: in the first one, a sort of impeller was used to agitate the water so that it can reach and wash the dishes; in the second one, the water was directly sprayed on the dishes by means of rotating sprayer arms (that is the solution commonly adopted nowadays). After the Second World War, the more favourable context gave a great impulse to the spreading of household appliances. In the early 50s, the first completely automated dishwasher was realized. This new generation of dishwasher was able to complete autonomously the whole washing cycle, thanks to electro-mechanical sub-systems. Nevertheless, these first automatic dishwashers were not efficient enough to completely eliminate handwork; however, their lack of acceptance at that time was largely attributed to the unavailability of detergent tailored for these machines. In the 80s, even if any radical and substantial improvement occurred in the washing technology, the dishwasher development has continued following emerging trends and customer requirements in terms of: safety; better use of the machine internal space; new aesthetic/ergonomic features; advanced resource saving technologies.

The above summarized dishwasher history is a typical example of a product evolution, from conception to maturity. Preserving this historical heritage can be a source of innovative ideas for designers and engineers [3]: they may not only "discover" solutions that were not developed because of a lack of adequate technologies, but also retrieve data to study the evolutionary trends of a technical system. On the other side, it is fundamental for manufacturers to preserve past experience knowledge, not only from a technical point of view but also in terms of how social and economical changes have influenced their product development process. Furthermore, people operating in standardization institutions can also better understand the needs of the contemporary technical world. Finally, the survey of the technical history can be an important tool for historians to study the step changes occurred according to socio-economic perspectives. These ideas are the embryos of the so-called Case-Based Design and Case-Based Reasoning approaches [4, 5], toward which the research activity may also evolve.

In order to make available and easily accessible the heritage of product and system innovation to all these people, a database has been designed to store the evolutions of machines and mechanisms. The data stored in this system are indexed on a functional basis which provides the taxonomy to model the engineering artefact under analysis [6, 7]: the primary index is based on the primary function, described by means of the paradigm <verb> + <object> + <characteristics>. For each product or system analysed, the key step of its evolution are identified through the analysis of patents/books or scientific publications. Up to now several products or systems coming from different industrial field have been already analysed in order to make the database more useful, increasing the amount of information available in it.

To introduce the description of the database structure, in this paper, the technical evolution of the solution-specific function "to remove food rests from dishes" is presented and discussed as a case study, being that functionality a specific case for the more general function "to remove mixture from an object". The examined machine that performs such function is the dishwasher. Regarding the dishwasher case study, it is worth to underline that the appliance industry make for a rich research context from the perspective of knowledge storing and management since the development of these products has to deal with complex problem solving activities in large-scale organizational settings.

Section II of the paper overviews the main steps of the dishwasher technological evolution: more then 100 patents have been selected and analysed in details while additional information has been retrieved searching into several technical and scientific repositories. Section III details the main technological changes that have characterized the dishwasher motor technology while Section IV describes the main characteristics of the database. Finally, the paper ends with a brief summary of conclusions and possible future research scenarios.

II. THE MAIN STEPS OF THE DISHWASHER HISTORY

In this section, a quick survey of the principal milestones that characterize the dishwasher historical evolution is proposed.

A. The birth of the first dishwashers

The Houghton patent [1] is the first, which one can find in literature, searching for machines that can wash dishes. It is worth noting that this patent refers to "a novel machine", while all the immediately subsequent patents refer to "improvements" of existing machines. The Houghton's machine was completely manually operated. Practically it consisted of a vessel that could be filled with hot water and a basket to hold the dishes. The basket was manually rotated by means of a crank handle. Mrs Cochrane, in 1886, greatly improved this machine since she introduced the sprays while the water pump and the dish basket were still manually operated [8].

B. The first elettrically powered dishwashers

In 1917, Mrs Cochrane came out with an improved solution: she introduced an electric motor to operate the centrifugal water pump (Figure 1) [9]. In this solution she also introduced the spraying arms, rotated by the reaction force of the water exiting through spray nozzles placed in these arms. In that model, the rinse phase was also introduced.

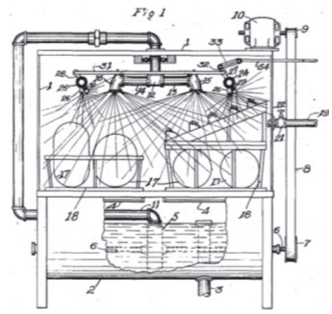

Figure 1 - Mrs Cochrane's patent: the centrifugal pump (5) operated by the electric motor (10)

In the same period (1921), the Walker Brothers Company patented a dishwasher machine [10] where an electrically operated impeller, totally immersed in water, was used to toss around the water and throw it on the dishes.

C. Towards automatic dishwashers.

In the 1950s, the automation began to appear in dishwashers. Even if these machines did not clean dishes well, their technological level started to improve quickly so that the transition from hand to automatic washing begun. The introduction of electric appliances in modern kitchens, has determined the born of a new era and the dishwasher manufacturers have seen a rapid increase of the production volumes for this appliance. From the historical point of view, in 1949 Apex Electrical Manufacturing Co. introduced a dishwasher called DISH-A-MATIC [11]. It was one of the first models of the post-war economic boom. In this model an electro-mechanical automation was introduced: a knob was used to control the washing cycle of the machine.

In 1954, Apex introduced another model. The dishes were washed by means of an impeller rotated by an electrical motor and the entire cleaning cycle (washing, rinsing and drying) was controlled by means of an electro-mechanical timer (based on several cams). In this model, electrical resistors were used to warm up water. In the related patent [12], that technical solution is motivated by the reduction of thermal energy dispersion in the hot water pipeline. In parallel, during these years, one can assist to the growth of dishwashing detergent producers that started to work in collaboration with appliance manufacturers and, specifically, with their technical departments: the relation among the detergent chemical action and the thermal and mechanical effects of the water were already known by experts [13].

D. Dishwashers from the 1980s to present

Starting from the 1980s, several improvements were introduced. Loading systems have evolved in an ergonomic direction as described in the advertising campaigns of that period. Two racks have been introduced in order to accommodate a higher number of kitchenware and make easier the loading phase. More rotating spryer arms have been introduced to improve washing efficiency. Detergents and rinse aid evolved to obtain a better result, forcing the dishwasher producer to adapt the machines to use the new products; tablets are a typical example: their use required a complete revision of the washing cycle and the introduction of adequate systems. Besides these mechanical and chemical improvements, electronic control systems were also introduced in this period allowing a more effective control of the washing cycle, and enabling the storage of more pre-defined programs.

Starting from that technological level, manufactures have then begun to explore new distinctive features thanks to a deeper understanding of the users' needs: changes in the way people interact with the dishwasher have been implemented together with the study of new cleaning/drying technologies (e.g. the generation of an ultrasound field to increase the water mechanical action or the use of the absorption properties of zeolite to improve the drying performances).

III. THE DISHWASHER MOTOR EVOLUTION

In the dishwashers currently on the market, a significant part of the electrical energy is used for heating up the water. However, in case of the heating element, it is worth noting that while in 1954 the electrical heating of water was preferred, nowadays the use of hot water is fostered to reach energy saving targets.

TABLE I. EVOLUTION OF DISHWASHER MOTOR CONSUMPTIONS

Year	Flow [l/minute]	Prevalence [m]	Power [W]
1950	200	7	600/700
1980s	120	5.5	110
1992	80	3.75	49
2012	60	2.7	26.5

TABLE II. BRUSHLESS AND INDUCTION MOTOR EFFICIENCY

	Used Power [W]	Motor efficiency [%]	Hydraulic efficiency [%]	Absorbed Power [W]
Brushless	25	75	52	65
Induction	25	53	52	90

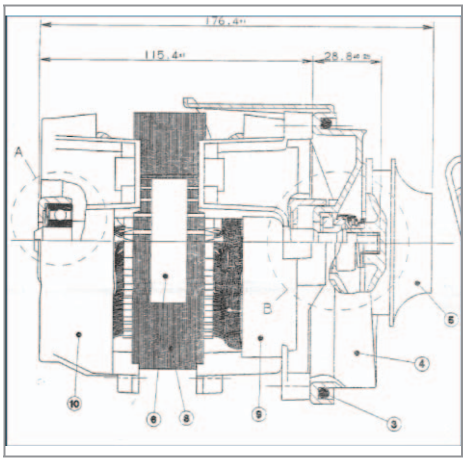

Figure 2 – A section view of a 1990s electropump

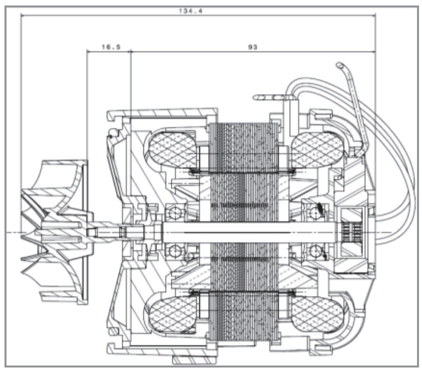

Figure 3 – A section view of a 2000s brushless motor with the impeller mounted on its shaft.

Additional electrical energy is used for driving the circulation pump motor and for the other electronic devices. This second aspect will be hereby analysed.

In the last 50 years, centrifugal pumps have always been adopted. Only their size and characteristics varied during this period while the type of electrical motors shifted from induction on to brushless. Specifically, the evolution trend of the motor and pump group has been driven by two external factors: the implementation of new washing techniques and the need for resource saving technical solutions (mainly in case of the amount of water and electrical energy to be used).

In the first years after the Second World War, the hydraulic power of the dishwasher was very high. Even if it is quite difficult to retrieve precise data, the SMEG *Niagara* dishwasher can be mentioned: its pump prevalence was higher than *7 m* and the flow higher than *200 l/minute*. The total electrical power of the motor was therefore quite high (up to *600-700 W*). More recently (1980s), the completely automatic dishwashers (i.e. appliance capable to wash, rinse and dry crockery without any human involvement) required a water flow of *100-120 l/minute* with a prevalence of *5-6 m*. The hydraulic power was then reduced to about *100 W*. The power of the induction motors (commonly used in that period) was about *300 W*, because of the energy loss in the pump (impeller and volute efficiency and the friction of sliding sealing). In the 1990s, the power (hydraulic and electrical) has been halved again, thanks to more efficient washing cycles and to the introduction of more effective detergents: motors started to become more efficient (Figure 2). At the beginning of the 2000s the brushless electric motors were introduced in the appliance (Figure 3). The use of these motors was made possible by the introduction of adequately sophisticated electronics, capable to generate and handle waveforms able to control the three-phase brushless motors. In these motors (smaller and with a higher electrical efficiency than the previous), the rotor consists of a rare-earth permanent magnet (neodymium is one of the more frequently used).

Table I summarize the evolution of the dishwasher motor performances.

Comparing the induction and brushless electric motors under an energetic perspective (Table II), obviously, it comes out that the increase of motor efficiency greatly reduces the power consumption. On the other hand, an increase in the hydraulic efficiency can determine a significant improvement of the energetic performances of a dishwasher as requested by current European standards focused on the energy efficiency of products [14].

IV. THE INFLUENCE OF CONSUMERS' NEEDS, STANDARDS AND MARKET TRENDS ON THE DISHWASHER DESIGN EVOLUTION

Appliance manufacturers are interested in continuously innovating their products to satisfy consumers' needs such as: excellent performances, low noise emissions, low energy consumptions and smartness capabilities. Having crockery perfectly clean without any damage, unwanted odours, food, spots and white residues is a must. To effectively respect such requirements, the following evolving working conditions should be taken into account: the innovations coming from the detergent industry, the changes in International Standards and the appearance on the market of new smart technologies.

Since the introduction of the first dishwasher, the chemical action of detergents has played a strategic role even if, according to manufacturer experience, the mechanical energy is the main actor in the removal of food rests and dirtiness. Detergent companies have then played an active role in determining the dishwasher evolution; one can find similarities among the main key-steps that have characterized these two industrial fields (i.e. the appliance and the detergent one) [15]: the birth of the automatic dishwasher powder in 1950s coincide with the introduction on the market of the first automatic dishwasher.

The European policies such as the so-called Energy labels [14] provide strategic guidelines not only to manufacturers in order to better stream their innovation efforts towards more energy efficient solutions but also to consumer, helping them to easily compare and judge the environmental behaviour of a product at the point of sale. Regarding the dishwasher, these directives identify three main energy classes: cleaning, consumption and drying. While the first and the third classes are based on performance indexes calculated according to specific criteria, the consumption class is measured in the amount of energy necessary to perform a standard washing cycle for a 12-place setting product. Future evolving scenarios [16] state that a reduction of the energy consumption of about 30% is still possible.

Finally, thanks to the introduction of intelligent logics the possibility to offer smart and high quality products is now becoming a strategic opportunity for manufacturers. Thanks to this step-change that is now characterizing the ICT field, with technologies at admissible costs even for a high pressure manufactured product such as the dishwasher, efforts are spent within R&D departments in order to: design multi-objective control logics to better manage the various input parameters of the product which influence its performances and its way of working; came out with innovative controls able to better regulate the pump motor in order to reduce noise emission and optimize the energy consumption; increase the appliance reliability to enable the early detection of fault conditions. The current trend is to increase the use of sensors, cabled or wireless, to gather information about the status of the machine.

V. THE DATABASE STRUCTURE

A. How data are collected

As briefly introduced in Section I, the information stored within the database comes from the analysis of machine and mechanism evolution performed by Master students attending the "Mechanical Engineering History" course at the Politecnico di Milano. During this course, students are asked to select among various products and/or systems of which they have to build the historical and technological evolution: the dishwasher is one of the about 250 products/mechanisms analysed. These historical analyses performed by students are the results of an intense search among several scientific/technical and patent databases. The aim of the course is to make engineering students more conscious about the importance of learning from past experiences. Studying the historical evolution of products they can retrieve two fundamental insights: firstly, the design of a new solution is also driven by non-technical requirements, that continuously evolve in accordance with the social and economical context; secondly, a successful design activity is the result of a harmonic and collaborative integration of several technical and non-technical expertise.

Together with this educational purpose, students, throughout their analysis are in part involved in the research activity whose aim is to define a database to store the steps that have characterized the development of specific technical solutions. Preserving that knowledge can help designers to better understand and make traceable the reasons of their technical choices and then face their evolution with a deeper awareness. Furthermore, even if some past solutions could have been abandoned for any reasons, such as the lack of adequate technologies or materials, the intent behind these solutions can, however, became the source of inspiration for new product changes. Hence, looking at history as a source of inspiration and knowledge is one of the main strength of the Politecnico di Milano “Mechanical Engineering History” course. A selection of students’ works is available online [17].

B. How data are stored

To store and index the analysed technical solutions or products an approach based on the functional basis developed by the National Institute of Standards and Technology (NIST) [6] has been adopted. Practically, the product is defined through a black box, which identifies just the main function of the system by means of input/output relations with the external environment. The main function is then defined by means of the following construct: <VERB> <NOUN> <PREDICATE>. The *predicate* is composed by two elements: <PREPOSITION>+<NOUN>. This construct has been derived according to one of the most spread representations in the area of engineering design [18,19] by adding the Predicate to make easier the search within the database [20,21]. It is also worth noting that the *predicate* is not a mandatory element, whereas *verb* and *noun* are required. Predicate can be used to represent the functional environment, as to say how or where the solution has to accomplish the action described by the <Verb> +<Noun> construct, or to better specify this action. For example, in case of a system having the function of transporting something, the more general and abstract representation of its main function can be formulated as <move> <solid>, where the first terms is the *verb* and the second is the *noun*. A designer can therefore search for this general function and retrieve all the available solutions (ranging from a space shuttle to the underground), or add a specification such as <on><solid>. The final resulting construct is then <move> <solid><on><solid>. Selecting this construct, the designer has already realized that he/she is looking for ground vehicles (e.g. trains, subways, buses etc.). The main benefit of this solution is a more complete awareness of the constraints that the designer is considering.

According to the NIST definitions and to the above-introduced construct, the dishwasher main function can be defined as: <<Remove><Mixture><From><Object>>. The term *remove* is intended with the meaning of: “To take away a part of a flow from its prefixed place”. A sander machine can be mentioned as an example: it removes small pieces from the wood surface to smooth it. The term *Mixture* is defined as “a substance containing two or more components which are not in fixed proportions, do not lose their individual characteristics and can be separated by physical means.” Finally, the term *Object* represents a “material that can be seen or touched and that occupies space”. It is worth noting that an object is a sub-category of a solid, according to the NIST terminology.

The described approach has been seen as a useful strategy to enable the knowledge to be easily stored and retrieved.

C. How data are structured

For each analysed product or system, the main steps of its historical evolution are indexed according to the construction previously defined. These historical evolutions practically consist of a sequence of records, one for each step. Within each database record, detailed information is reported to

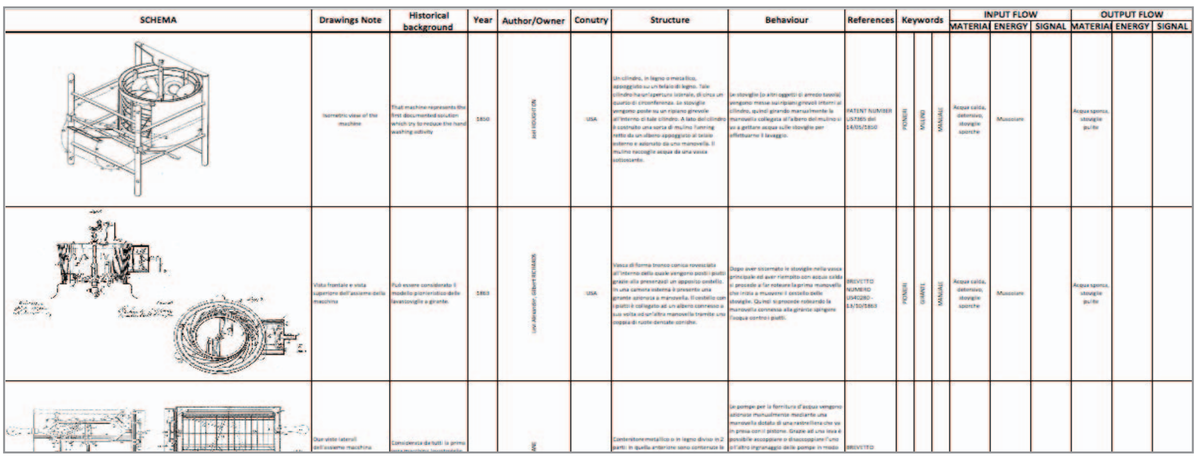

Figure 4 – The database records: an example from the dishwasher case study

describe the main constructive solution that characterizes each step. Even if the main function of the product or of the system under analysis should not change along its evolution, its input/output flows could vary: it is then also important to take into account and collect these changes. In particular, within each database record the following information is stored (Figure 4): a schema of the solution with comments; the solution affiliation (e.g. year, author/owner, country); a brief structural description of the solution (i.e. the list of the main parts/components and how they are interconnected); the solution behaviour (how the structure operates in order to achieve the main function); references to additional internal/external data.

At the present stage of the research, each historical evolution is stored in a MS Excel files. This very simple storage system has been chosen since it easies the data entry phase performed by students (each group works on a specific solution), and because it can be quite easily converted into a more sophisticated data base management system (DBMS) (e.g. MySQL, SQL Server). All the Excel sheets are organized into two hierarchical levels: in the first, functions are stored according to the construct previously described, while in the second such functions are specified into different implementing solutions: for example a dishwasher, a washing machine and an industrial vegetable washing machine (that belong to the 2nd level) can be all linked to the general function "remove mixture from object" (1st level).

By means of filtering features, it is therefore possible to extract a function or a group of functions, and then to explore only the relevant solutions. When the data will be stored in a DBMS, further queries could be planned, in order to allow users to search for other characteristics (e.g. input and output flows of material, energy and/or information).

VI. CONCLUSIONS

In this paper, the evolution of the dishwasher electric motor has been described together with a more comprehensive view of the main key steps that have characterize the dishwasher history: not only technical, but also social and economic factors have been investigated. From the analysis it brings out that the evolution of electric motor has been strongly driven by energy and resource saving targets: the introduction of electronics, able to effectively manage the motor and the whole machine operating cycle, has then represented a fundamental step to reach such environmental purposes. That historical analysis has been performed with the involvement of students attending the "Mechanical Engineering History" course of Politecnico di Milano. In this course, students learn the importance of such kind of analysis and how to correctly perform them. Their involvement within the research activity is guided by the intent of making them more conscious about the usefulness of the work done: when the database will be made available, it will become a source of precious information for engineers, scholars and institutions.

Regarding the database, additional effort will be put to improve it, increasing the amount of information available and improving the way it can be navigated.

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